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by

J. E. Deverall

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ABSTRACT

A water heat pipe was operated while being subjected to typical sinusoidal and random vibrations encountered during a missile launch to determine the effect of vibration on heat pipe performance. The results of the experiment indicate that vibration tends to improve heat pipe performance as it promotes better wetting of the wick structure by the fluid.

I. Introduction

The heat pipe[1] is a heat transfer device which has considerably less weight and orders of magnitude greater thermal conductance than any type of solid heat conductor. It is a sealed container in which a fluid is continuously evaporating and condensing, transferring heat by mass flow and utilizing the latent heat of vaporization.[2] A complete flow cycle is formed by return of condensed liquid to the evaporator through a capillary wick structure. By proper choice of fluids, heat pipes can be constructed for operating temperatures from below 0° to 2000°C.[3]

Because of the heat pipe's high thermal conductance, light weight, and ability to transfer heat with essentially no temperature drop, it has great potential for the solution of heat transfer problems in space applications. The thermal problems encountered in satellites range from low temperature thermal control,[4] where water heat pipes could be used, to high temperature heat rejection systems and thermionic power devices in the liquid-metal heat pipe range.

To establish the fact that heat pipes will function properly under space conditions, an experiment was conducted in which a water heat pipe was operated in an earth orbit. The results of that experiment indicated that the absence of gravitational forces was not detrimental to heat pipe performance.[5] In many space applications, however, it may also be necessary for a heat pipe system to operate during the launch period which would subject it to rather severe vibrational forces. The object of this experiment was to investigate the effects of sinusoidal and random vibrations, similar to missile launch conditions, on the operation of a water heat pipe.

II. Heat Pipe Assembly

The heat pipe used for the test was a 12 in. by 3/4-in.-o.d. stainless steel tube lined with three layers of 100 mesh stainless steel screen to provide a wick structure. Closure of the pipe was made by welding an end cap into each end. A 1/8-in.-o.d. annealed nickel capillary tube, welded into one end cap, provided a means for sealing the fluid under vacuum after loading.

Heat was supplied to the heat pipe by a copper-clad electric heater which was wound around the pipe and soldered in place with pure tin for a good mechanical and thermal bond.

After the heat pipe was assembled and helium leak-tested, it was loaded with the proper amount of distilled water. The pipe was first evacuated for several hours until the pressure was 10^{-7} mm Hg. The vacuum line was then sealed off, and a valve to a pipette containing distilled water was opened. When the desired amount of water had been metered into the heat pipe, the pipette valve was closed. The pipe was sealed by cutting the annealed nickel capillary tube with a pinch-off tool. The amount of

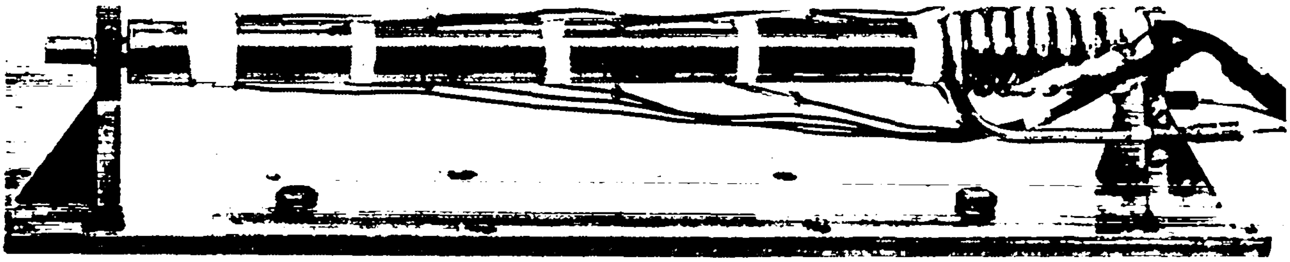

Fig. 1. Heat Pipe Assembly.

water required to saturate the wick, with no excess, was 7.5 g.

The heat pipe was supported between two brackets which were attached to an aluminum baseplate, with the bracket at the heater end 1/8 in. higher than that at the condenser end. This was done so the heat pipe would have a slight pitch when the baseplate was mounted horizontally, to ensure that liquid return was by capillary action. The heater leads were supported by clamping them to the bracket at the heater end. The complete assembly is shown in Fig. 1.

III. Instrumentation

Temperatures along the length of the heat pipe were measured by chromel-alumel thermocouples spot-welded to the surface of the pipe. The thermocouples were spaced along the length, as shown in Fig. 2, with six placed along the top surface and six underneath. A 12-point recorder, with a sweep-rate of one temperature reading per second, was used to record the temperatures. A variable transformer provided control of the heater input power to obtain the desired temperatures.

IV. Vibration Equipment

The facility used for this experiment was a Ling Electronics vibration exciter with a 90-kW output power amplifier and an 80-filter automatic equalization-analyser console for random vibration testing. The exciter had a frequency range of 5-2000 cps, and the rate of frequency change could be programmed for automatic control. A remote frequency meter, connected to the control room, was placed beside the exciter so that the observer could note the frequency on the temperature recording sheet as a function of time.

A small bench-model vibrator was also used to test the heat pipe performance when operating at different angles. This was a 60-cycle, constant frequency model with a variable force input.

V. Test Procedure

For the variable frequency and random vibration tests, the heat pipe assembly was bolted to the Ling exciter in a horizontal position. The mounting arrangement is shown in Fig. 3 with the temperature recorder and variable power supply in the background. Sinusoidal and random vibration tests were made at two different heat pipe equilibrium temperatures, 60° and 90°C. The following specifications were used for the tests.

Sinusoidal Sweep

5 - 45 cps @ 0.125 inches D.A. displacement
45 - 165 cps @ 12.0 G's peak
165 - 2000 cps @ 9.0 G's peak

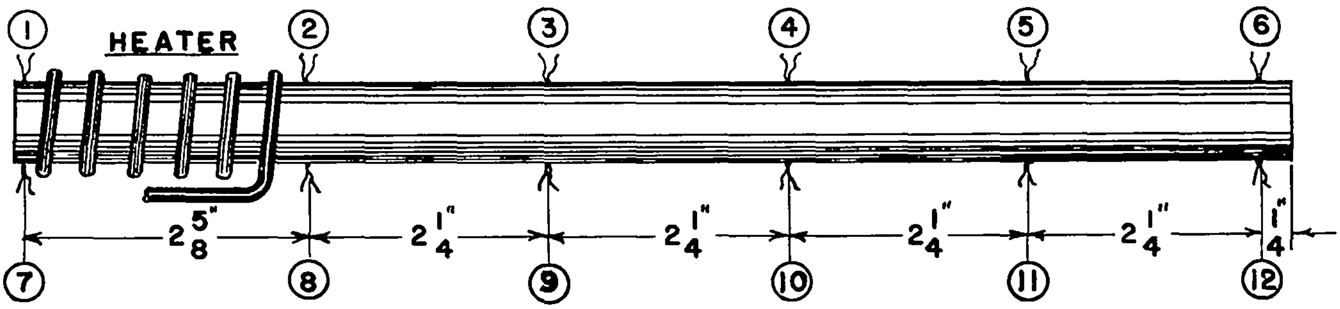

Fig. 2. Thermocouple Spacing.

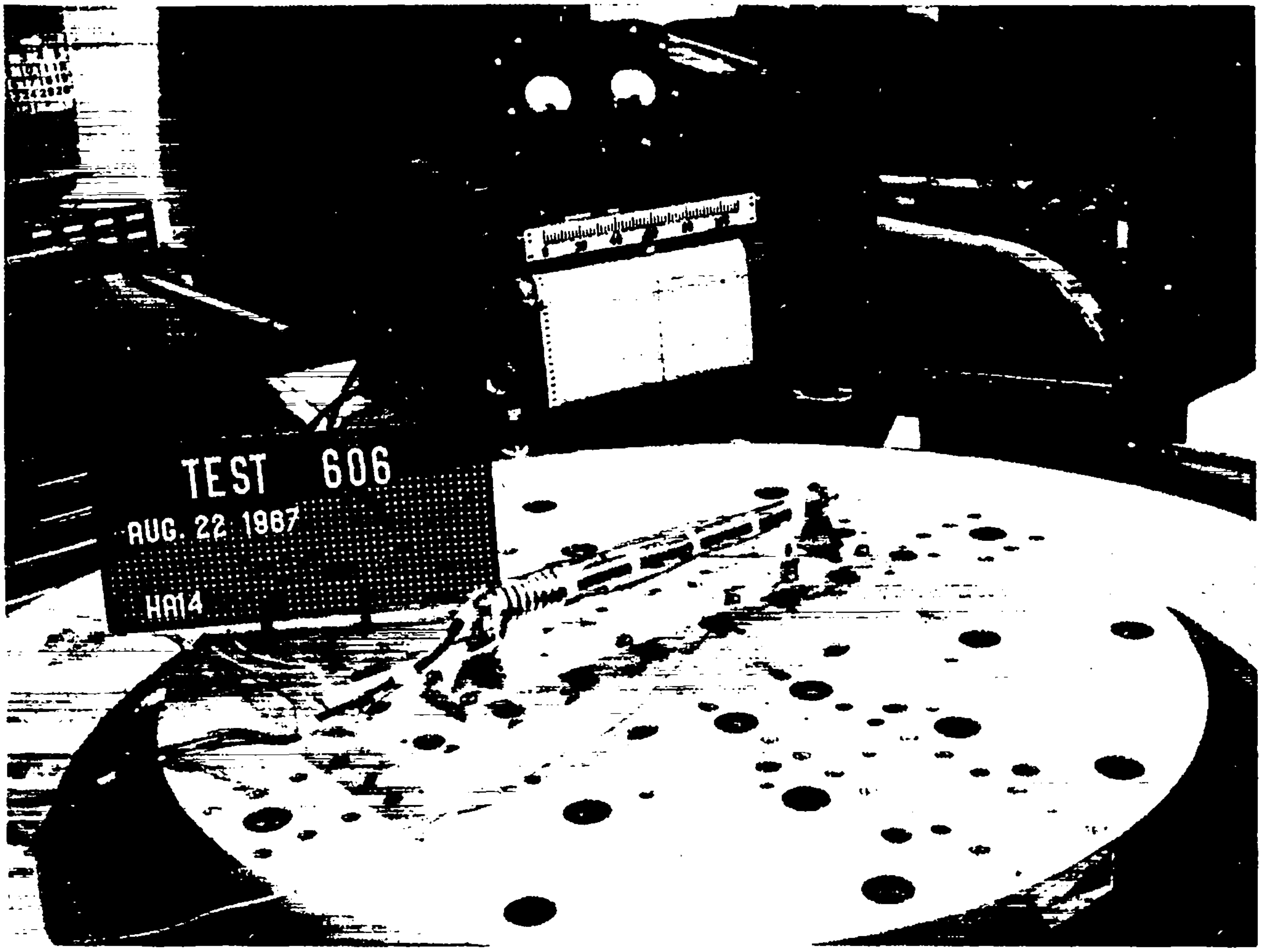

Fig. 3. Heat Pipe Mounted on Vibration Exciter.

Random Vibration

20 - 65	cps @ 0.04 G^2 per cps
65 - 125	cps @ 9.0 db per octave
125 - 700	cps @ 0.3 G^2 per cps
700 - 915	cps @ -18.0 db per octave
915 - 2000	cps @ 0.06 G^2 per cps

The sinusoidal sweep was started at 5 cps and increased to 2000 cps at a sweep rate of 3 minutes per octave. The random vibration test was run 4 minutes at each temperature level.

At the start of the test, the power supply was turned on and adjusted until the heat pipe reached an equilibrium temperature of 60°C. The sinusoidal vibration sweep was then started, and the frequency, as indicated by the remote frequency meter, was recorded at various intervals on the temperature recording chart. When this phase had been completed, the heat pipe was then subjected to the random vibration. During both tests a continuous monitor of the temperatures was made by the temperature recorder. The heat pipe temperature was then raised to 90°C and the two tests repeated.

For the 60-cycle vibration test, the heat pipe was operated at 70°C with the heater end elevated at various angles from 0° to 40°. The heat pipe was bolted to the vibrator plate, and the angle was varied by elevating one end of the vibration unit as shown in Fig. 4. At each angle, the heat pipe was allowed to attain temperature equilibrium and then the vibrator was turned on for 1 minute. In an effort to observe the effect of vibration on the distribution of the fluid in a heat pipe, a Plexiglas model with no heater was also tested. In this model the wick structure did not extend the full length of the tube so that a transparent

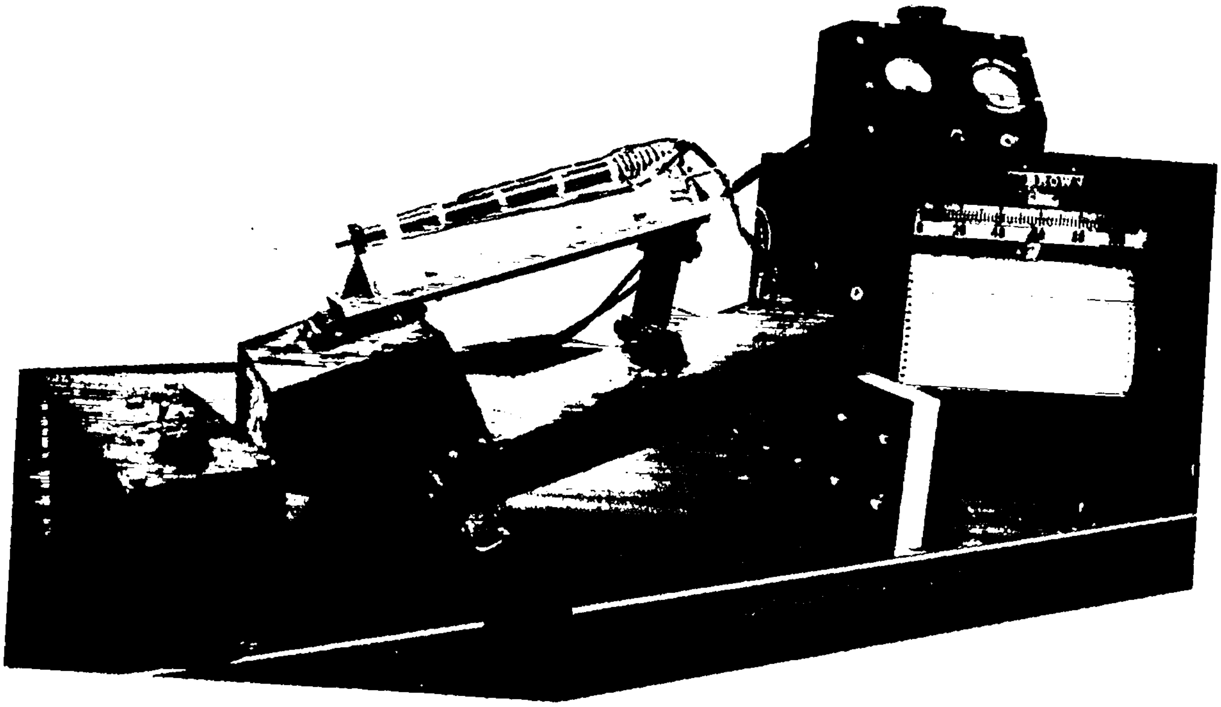

Fig. 4. Vibration Test at Various Angles.

section at one end permitted observation of vibration effects on a liquid pool (see Fig. 5).

VI. Results

At the beginning of the sinusoidal sweep test, the heat pipe was essentially isothermal at 60°C except at point No. 12 which was 3/4°C low. This was due to a slight amount of excess liquid collected at this point. During the vibration sweep there was no change in the temperature distribution except between 500 and 1000 cps. In this range, temperature reading No. 12 increased to 60°C

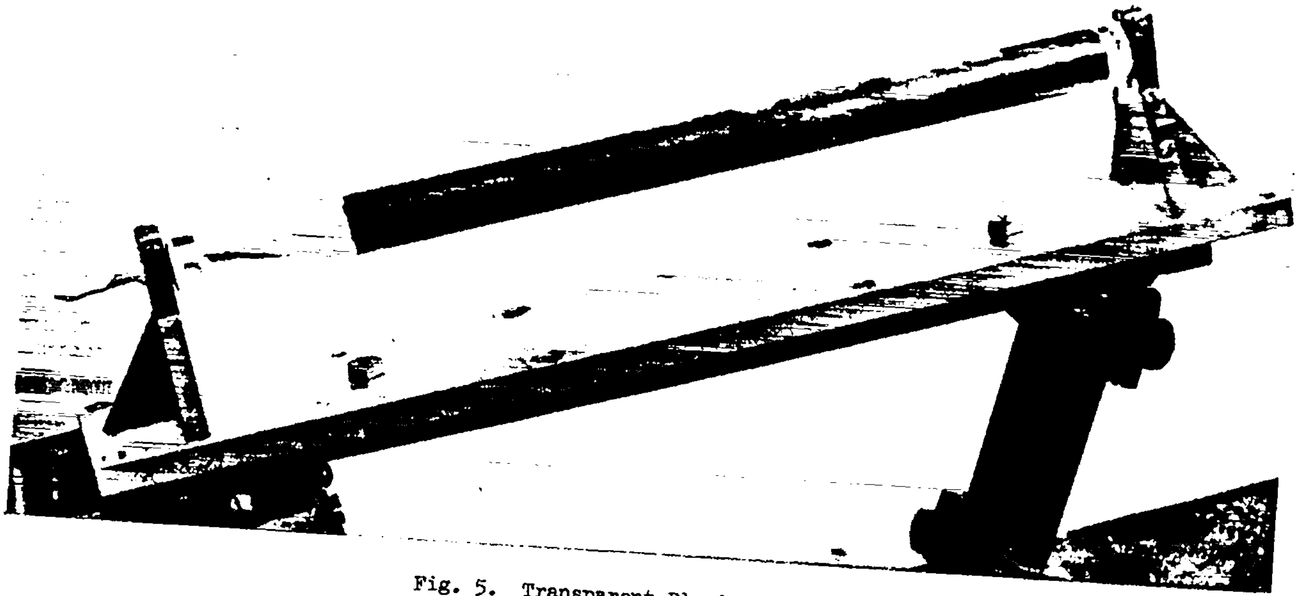

Fig. 5. Transparent Plexiglas Model.

and all temperatures plotted as a straight line. At this temperature there was no change in the temperature distribution during the random vibration test.

When the temperature was increased to 90°C, point No. 12 was approximately 2°C low because the quantity of excess liquid was larger owing to thermal expansion of the liquid. During both the sinusoidal and random vibration tests this temperature difference was only 1°C.

In the 60-cycle test, the amount of excess liquid at the end opposite the heater increased with the angle of inclination of the heat pipe, owing to draining of the wick structure. This led to a lower temperature at the end of the pipe. At 40° elevation, the wicking-limit height, thermocouples No. 6 and No. 12 indicated temperatures of 7° and 12-1/2°C, respectively, below the other pipe temperatures. A radiograph at this angle showed that the liquid pool was large enough to contact both of these temperature points. However, when the vibrator was turned on at each of the angles tested, the temperature differences disappeared and the heat pipe operated isothermally within 1°C.

The Plexiglas model was tested in an effort to determine what caused the heat pipe to operate isothermally under vibration. It was observed that a pool of water, formed by inclining the pipe, was broken up into small droplets and thrown back up into the wick structure. It was also noted that when the wick was almost completely drained, it would re-wet much faster and more completely under vibration.

VII. Conclusions

The results of these tests indicate that sinusoidal and random vibrations, within the spectrum tested, are not detrimental to heat pipe performance. It was considered possible that vibration would remove liquid from the wick structure; however, these tests show that vibration aids in the wetting of the wick, forcing liquid into all parts of the wick structure, and improves heat pipe performance. In fact, it appears that after heat pipes have been loaded with fluid, the wetting-in process could be greatly accelerated by applying vibration.

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